A SKETCH OF THE HISTORY OF REFLEX ACTION.

I.

INTRODUCTORY.

A number of the phenomena, normal and especially morbid, which we now group under the physiological category of reflex action, are noted in the earliest medical literature. The Hippokratic writers not only knew of a general consensus between different parts of the body—such as that existing between the uterus and the breasts—but in their sections on the sacred disease, or madness, it is easy to see that various forms of reflex cramps, although wrongly understood, had been often observed.

Galen even describes correctly the effect upon the aperture of the pupil, of closing and illuminating the eye, and treats of diseases and abnormal symptoms which arise from "sympathy." The history of medical studies, before the great anatomists of the sixteenth century had demonstrated the existence of nerves as distinct from sinews, records many instances of "sympathy," mediated, it was often said, by the blood-vessels. Some of these are purely fanciful, some are due to other causes, but not a few are true reflexes. It is impossible to approach our subject without asking at the outset why the simple rubric of reflexion, which now explains so much, was not suggested by the phenomena so often observed before the second quarter of our own century. The answer is not, however, far to seek. Besides the meagreness of anatomical knowledge, there was a deeper and more generic cause, suggested by the very word "sympathy." It was the belief in an immaterial psychic principle pervading the whole body and mediating freely between its parts, *without necessitating a direct connection of tissues.* This general notion which long prevented any adequate conception of reflex movements, and which, as we shall see later, is still cherished by a few uncritical scientific men, is no less universal and spontaneous than language itself, in the earliest known forms of which it is so manifoldly seen. It is nothing more nor less than spiritualism, or animism, beginning, as it naturally does, in the form of psychological dualism, at first with the suggestion of a refined essence, intangible as a shadow, separable from the body in dreams, vital as the breath, finally surviving death and endowing animals, plants, inorganic things, and even the

elements of the world itself, with a distinct animating, if not a free and more or less conscious principle. The supposed subtle operations of this principle have been often characterized. It will answer our purpose here merely to recall to mind a few not unfamiliar historical *motifs*, which we wish might serve to broaden the narrow and conventional lines wrongly followed in the so-called "history of philosophy."

In the rudimentary physiology and pathology of nearly all the Greek philosophers, the *pneuma* or *psyche* plays the chief rôle. Plato, the great protagonist of all modern animistic philosophizing, conceived the soul, as, at the same time, the principle of life, and as independent of the body. It thought in the head, felt in the breast, and desired in the belly. It was closely connected with the world-soul, while over the material world the *idea* reigned supreme. Aristotle, who may be said to have given form to the mediæval Christian philosophy, and especially to its psychology, as well as to have first taught the development theory and the doctrine of the powers or faculties of the soul, recognized a nutritive soul in plants, a sensory soul in animals, and a thinking soul in man. As the principle of life, it was inseparable from the body, while the thinking *nous* was immortal. It was the sufficient cause of all the phenomena of life. Its chief seat was the heart, and it was mediated by fire, air, or ether. The Stoics, the pneumatic school of medicine, and even Galen believed the body pervaded through all its faculties by vital or intelligent forces. The cabalistic systems of emanation, which so effectually extinguished medical knowledge and art after Galen, taught that demons, once united near God, fell, and now pervade all nature, giving it harmony, "as the human body is pervaded by sympathies." Diseases, especially those of the nervous system, were ascribed to the presence of devils. The physician must not so much study magic, which was suspected, as science came to be later, but must struggle up by prayer, asceticism and extasy to gain the theurgic power of exorcism by knowledge of and living union with the omnipotent, spermatic Word of God. Meanwhile, devastating plagues and fantastic neural diseases—lycantrophy, obsession, dancing and self-scourging manias, and the children's crusade, which Hæser, in his history of epidemic diseases, well describes as a "psychic pest," were explained on this principle.

Cardanus taught that there was a sympathy between certain parts of the body and certain planets. Paracelsus, whose vagaries overthrew the authority of Galen, asserted that the soul itself had a soul, and that had another, and so on to the fifth potence or the quintessence. He taught the existence of a sidereal and an astral, as well as a material body, and

assumed a conscious vegetative principle or *archæus*, which separated the good and the bad in food, fed the various organs and kept them at work, and must occasionally be roused by medicine or otherwise from forgetfulness of its duties. According to the Rosicrucians, medicine rests on a knowledge of universal harmony. Plants suffer our diseases, and all diseases have their real seat, not in the material organism, but in an animating principle. Thus the sympathy of medicines, of which they wrote, was no mere metaphor to their minds. Not only was the existence of a panacea, as the counterpart of poisons universally deadly, asserted, but it was assumed that all diseases had at bottom one occult, immaterial cause, and must also have one cure, which was to be spiritually sought, discerned and applied. Thus medicine was connected with Christology. Croll asserted that all nature was alive, and nothing was dead. Man is made after the pattern of the firmament. All that exists in the world at large—even minerals and plants—exists also in microcosmic man. Every herb represents a star and every star an herb; and the doctor who is regenerate by the light of divine grace knows the magnetic star-lent influences by which all medicines work, and the mysterious signatures in accordance with which they must be applied. Later it was said that every organ had its vital part. We even read of a vital astronomy; and all nature was animated by sympathies and antipathies. As Geulincx declared that mind and body were so distinct and opposed that they could affect each other only through a divine mediation, so Helmont taught that no medicine could take effect save through "the gracious compassion of God." Disease, it was repeatedly urged, was not merely an accident or a substance, but a struggle of the vital forces against the invasion of a morbid species or principle. Near the end of the seventeenth century, many of these conceptions were combined in the influential theory of Stahl, that the soul must be assumed as the one only immaterial and active principle in the body, the latter, as material, being absolutely passive. Every physiological process and movement whatever is the work of this rational and intelligent, although not always conscious or reflective soul. Fever, e. g., Stahl regarded as the excreting, secreting, circulatory processes of a sound soul resisting some noxious agent or activity, and as impossible in animals because they have no soul.

The influence of such conceptions has, fortunately enough for the human race, ceased for the most part to influence the theory or the legitimate practice of medicine, although they are common and potent enough among uneducated and quackish physicians. In the natural philosophy of Schelling and

Oken, the spiritualistic conception obtained a very strong hold of the popular half-cultured mind, which it still fascinates in the form of Hartmann's exposition of the Unconscious, in Hæckel's speculations about the cell-soul, etc. Here too, as we shall explain later, we believe the theories of Whytt and Pflüger, and their rehabilitation by G. H. Lewes, must eventually be classed. That chapter of it which treats of nervous functions has been longest and most dismally obscured by the same class of superstitions which science has had to oppose in some form at every step of its progress. It is plain that if corporal functions are mediated by immaterial agencies, physiological science is impossible. If, between a stimulus and the reactionary movement in the leg of a freshly decapitated frog, any sort of a sensory or volitional process is interpolated which is different from, or can in the least degree affect the train of mechanical or chemical activities in the tissues, it follows that just in that degree all inferred laws concerning the action of reflex centers can be only conjectured as far as their more broadly philosophical bearings are concerned. These spiritualistic superstitions were indeed opposed not merely to the principles and methods of science in general, but were eminently inconsistent with such fundamental schematisms as sensation and motion, feeling and will, stimulus and reaction, etc., the slow development of which by the Montpelier school and elsewhere gradually paved the way for a neuro-psychology which came to regard reflex action as the element, rudiment, type or unit of mind.

Again, it was frequently said that sympathies were mediated by the blood vessels. This seems like at least an attempt at a physiological explanation. This doctrine was, however, closely connected with early spiritualistic conceptions on the one hand, and with an erroneous conception almost universally held, in some form, for nearly a score of centuries, on the other. In the first place, in dead animals the arteries being found nearly empty were thought by the ancients to be filled from the lungs with air or ether, as their name indicates. Ether, according to the extended and influential Pythagorean school, was the highest and purest part of the air, the medium in which gods, planets and immortal souls live serenely, in eternal motion. Demokritus taught that the psychic nature was inhaled constantly from the air. The soul of man was thus called a product or part of the world-soul. Diogenes made air the first element, and said that life and thought were given in or with it. The Hippokratic school explained, further, that, after reaching the arteries, the ether passed to the brain, where it left the "bloom of its forces," increasing sensibility and mobility, and thence flowed to other parts of

the body, which are vital in proportion to the nearness of their vascular relation to the brain. By a curious confusion of the two stand-points, the brain, and not the heart or diaphragm, as many supposed, was made the seat of feeling and knowledge, while at the same time it was regarded as a gland that cooled and tempered the heat of the heart by secreting phlegm which, if its passage downward and outward was checked, caused epileptic cramps, *tetanus, spasmus, cynicus*, madness, and a disease which seems to have been *tabes dorsualis*.

Hence, it was inferred that such diseases, which have played so important a part in the early history of religion, were no more holy than others, need no expiation and are cured, not by magic, but, like all diseases, by applying the counter-cause. Hence, too, the great influence ascribed to winds, weather, and the location and frontage of houses, to which so much space is devoted by this school, in a fashion so eminently sanitary and in accordance with the customs and climatology of Greece, and which can be traced in astrological vagaries that haunted therapeutics for many centuries. The "powers of the air," the rushing wind or *spiritus*, the higher pneumatic nature of man, concentric airy spheres peopled with more and more heavenly natures as the soul ascends, and many other widely current conceptions of primitive psychology, show how deeply inwrought was the notion of an airy, etherial soul pervading the whole body, no less effectually than the blood-gasses in the processes sometimes grouped together by modern physiology as "internal breathing." Plato thought taste was mediated by small blood-vessels which pass from the tongue to the heart, and hearing by the motion of the air being carried over into the blood. While the brain was spongy, moist, and the seat of cold which tended downward, the heart was the source of heat and fire which tended upward, to prevent the too lavish efflux of which the eye-lids were designed. From the notion of the sacredness of blood as a medium of the soul, came the subtleties of the pulse-feelers, who distinguished a score of fantastic kinds of pulse from which they practiced divination, as was later done with the urine of which nineteen colors were distinguished, as well as the sixty species of fevers described in the fifteenth century.

Again, sympathies were mediated not by the blood directly, but by animal spirits secreted from it in the ventricles of the brain, the systole and diastole of which caused them to circulate along the nerves through the body. One mediæval anatomist describes the optic nerve as having the form of a hollow tube, so that the visual spirits might pass, carrying the ideas from the air and idola from objects to the brain. Such conceptions, gathered almost at random, will suffice to

illustrate the general psycho-physic notions which prevailed until Harvey, in the first half of the seventeenth century, demonstrated the circulation of the blood, and which for a long time prevented the acceptation of his theory. Even when he urged that in the embryo, at least, blood and not ether must circulate in the arteries, it was replied that one, as well as the other, could be derived from the mother. It was far easier, one antagonist urged, to conceive fine meshes in the walls of the heart, perhaps closed after death, through which air entered from the lungs, than to imagine the fine, invisible capillaries which Harvey assumed all over the body, connecting arteries and veins.

Toward the end of the sixteenth century, before Harvey had made his observations, the opinion began to gain ground among anatomists, that the sympathies were mediated by the nerves which were beginning to attract great attention. This was in some sense established by Willis, who was the best anatomist of the seventeenth century. Where two parts of the body were in sympathy, he inferred that they were connected by nerves instead of by blood-vessels. This opinion was current for a long time. A glance at the neurology of this period will suffice to show that, although much was done by the great observers whose names are preserved in the nomenclature of the brain, they were very far from attaining to any adequate conception of the functions of a nervous center, or even of nervous fibres. But a few decades before Willis wrote, one observer had urged with great vigor the Aristotelian theory that the nerves took their rise from the heart, because the soul, being one, could have but one seat and that must be the heart, which was the first point of motion in the impregnated egg, and was immediately affected by every emotion.

The arteries, which conducted nervous energy from the heart to the brain, had a nervous envelope, and after their cavities had united in the brain, their walls divided as nervous threads. Although the animal spirits were secreted from the blood of the *choroid plexi*, Servetus said the proper seat of the soul was the aqueduct of Sylvius. The first and second ventricles, he explained, received images from the external world; the third was the seat of thought, and the fourth of memory. The cortex and convolutions of the brain were neglected, the base and centre attracting chief attention, in spite of the old notion that the outer membrane enclosing it, in which it was long thought the cerebral nerves in part took their origin, was essential to psychic processes. When Fallopio urged that only the optic nerve was enclosed by a membrane of the dura mater, it was for a time thought that this

was a peculiarity of sensory as distinct from motor nerves. Long, and sometimes bitter, was the controversy, whether the optic nerve was really hollow, that the visual spirits might reach the eye; whether the brain had more veins than arteries; whether it was a gland and the glands nervous; whether nerves contracted and relaxed; whether the cerebellum had nerves of its own; and at what point the soul was most probably located. The *corpora striata*, according to Willis, was the seat of sensation, while the activity of the soul was chiefly concentrated in the *corpus collosum*, on the surface of which ideas were mirrored as on a white wall. A whitish nervous sap is the vehicle of the animal spirits. Others, influenced by Newton's discoveries, argued for a solidary structure of the nerves, and the theory of nerve-vibration, analogous to the undulations of ether, was generally adopted by English physiologists. On the one hand, it was urged that the vessels about the circle of Willis were the centre of sensation, and the *dura mater* was that of motion; while in Italy it was thought that the latter enclosed four ventricles like the heart, and was the centre from which nerves proceeded, like the blood-vessels from the heart; and finally, that it was loose enough to beat like the heart, as its analogous fibrous structure indicated. Thus all the movements in the body which were effected by nerves were ultimately caused by the force imparted to them from the *dura mater*, the movement of which aided the circulation in the brain, secreted the nerve juice and diffused it throughout the nervous system, and the extreme sensitiveness of which indicated that it was the seat of all sensation. It was reserved for Haller to demonstrate that the *dura mater* was immovable, insensitive, and was not the origin of nerves. Thus sympathy or consent, although rightly located in the nervous system, was not much nearer a correct explanation than when it was thought to be mediated spiritually, or through the blood-vessels.

A fourth theory, more important for our theme, took its origin in the epoch-making discovery of the father of German physiology, Haller, which properly dated with his communication to the Göttengen Academy, in 1752. He had tested a great number of tissues and organs, and found that the irritation of some caused sensation, and that of others caused movement or contraction. Only those parts which contained muscular fibres could contract, while nerves were not irritable because they could not move. He found that muscles were irritable some time after they were separated from the body, and compared the contraction of the fibers of the heart caused by the blood, with that of the voluntary muscles, caused by the will. Irritability he found constantly present in the

muscles while nervous force worked through the will, the result being the same in both cases. Hitherto every force tolerated in the animal body had been either closely analogous with known chemical or mechanical forces, or else had been regarded as more or less spiritual. Haller analyzed the hitherto inexplicable functions of motion, and found an elementary power inherent in muscular fibres, which was always present and aroused by irritation, and which had no parallel in inorganic nature. Haller was moderate and rational, and regarded irritability only as a power peculiar to and inherent in muscular fibres. The long discussion of his discovery that followed, and which for a time eclipsed nearly every other question in medical science, equals, if it does not exceed, in vagaries the philosophical speculation consciously and unconsciously suggested or fashioned upon the demonstration of magnetism and electric polarity. Whytt declared that all parts of the animal body were sensitive, whether containing nerves or not; and that the so-called irritability was a psychic activity. Some feared a rehabilitation of occult qualities in the doctrine of irritability. Some thought that all muscular action depended on nervous fluid or the *vis nervosa*. One writer said that only nerves could excite the vital molecular activity of contraction, and not a few argued that diseases were caused by means of medicines working upon irritability. Irritation and stimulus henceforth became dominant conceptions in pathology.

Gaub distinguished the soul, to which he ascribed not only the instincts but even respiration and vital force, and defined the latter as the power by which living matter contracted under the influence of irritation. Living matter is matter that can contract and feel, and an irritation he explains as that which, by contact, excites vital force to action. In his Pathology, however, he uses the word irritability in quite a different sense, as increased activity of the vital force, and as such, opposed to torpor. Vital force, he argued, was something unique and not to be sought in the elements of organisms, for these could still subsist when it was gone. It was not even to be confused with the electric or nervous fluids, which two latter some identified. Barthey added to irritability in muscles a "dilatation-force," and regarded their rest as active. Gregory thought irritability was to be distinguished from nervous force only by its seat, and, besides a dead elastic force in muscular fibre, described a third "tonic force," which resisted their relaxation. Schäfer regarded sensibility as independent of its material basis and essentially identical with vital force, while irritability depended upon it. Some located irritability in the solid, others in

fluid parts of the body. Many said everything which can react is irritable, thus extending the notion to the whole body; while scores of speculations for which we have no space and the reader would have no patience, were freely indulged in.

Haller's conception of irritability rested upon the phenomena observed in the heart, which he supposed to be without nerves. This error was natural enough when we consider that the nerves of the heart are so small that only the most accomplished microscopists can trace them. Only one observer seems rightly to have understood, and to have effectively contributed to the development of Haller's conception of irritability. Fontana, in his classical experiments, published in 1775, demonstrated the difference between irritability and elasticity (which continued its oscilations after the cause was removed) on the one hand, and the *vis nervosa* on the other. He showed that every stimulus diminished, while rest increased, irritability. He agreed with Haller that the nervous agent was the exciting, but not the immediate and sufficient cause; that in most cases it acted as the external excitor of the irritability of the muscular fibre. By the discoveries of Galvani, near the beginning of the present century, attention was called to the phenomena of nerves acting under electrical stimulation, and the important question whether muscles were irritable without the mediation of nervous fibres, was demonstrated after the effect of *curara*, which destroys the action of nerves upon muscles was discovered, independently and about the same time, by Kölliker and Claude Bernard. This we may regard as a triumphant vindication of Haller, whose work resulted in exorcising from muscles—the last excited element in the "reflex arc"—the mystic notions of vital force, and in opening up the broad and fruitful field of myology to scientific methods.

Although Haller had found that certain parts, such as the pleura, the bronchi, etc., responded to stimulation neither by sensation nor motion, another important result of his experiments was to cause functions and parts to fall into two great categories, one sensory and the other motor. This important dichotomy, which still underlies most conceptions of reflex action, also began at once to play an exceedingly conspicuous part in medical and philosophical theories. The notion of vital force was, in fact, as some complained, divided into two principles. Sensibility was paralleled or contrasted with irritability at every point. The mystics and followers of Stahl substituted motility, or perhaps, like Borden, voluntary motion, as the second term of the two elementary physiological phenomena. Many translated irritability in the freest and loosest way, as the power of reacting upon outer impressions of

all sorts. Even subjective phenomena, such as pain, reflexion, etc., were characterized as higher manifestations of irritability. In the system of John Brown, which became so influential on the continent, excitability was said to be located in nerve and muscle substance, and was defined as the property of being called into self-activity by the action of external stimuli; and was made the specific, though otherwise unknown, characteristic of living matter. The latter tends at every point and movement to fall into its simpler elements, but is forced to continue the processes which constitute vitality by external activities ever incident upon it in all directions. Too much of the latter causes hypersthenic; too little, the asthenic diseases. Life is thus reaction, and all its processes are made up of stimuli, excitability and excitement.

The only physiological fact upon which this class of speculations rested was the observation that the stimulation of certain nerves seemed to cause only sensation, and that of others only motion.

The discovery of the Voltaic pile, with its negative and positive pole, was immediately seized upon with the greatest avidity, and became the fundamental category, now in more now in less disguised or conscious form, for a mass of medical and philosophical speculation. Life, it was said, was analogous to, if not identical with electricity, and the intellectual world seemed to fall apart into the quaint electric dualisms of active and passive, male and female, day and night, thought and feeling, acid and alkali, etc., etc. Many preferred to regard the universe as made up of triads. Oxygen, hydrogen, and carbon were often suggested, but under the influence of Blumenbach, and especially of Schelling, the triad, reproduction, irritability, sensibility, as ascending potencies of the absolute, revealed successively in the ascending orders of animal life, gradually unfolded into speculative forms which Humboldt well designated as the saturnalia of natural science. Hegel is preëminently indebted to Volta for his unique dialectic method of affirmation or position, negation, and mediation or indifference-point. Meanwhile, medical art and science gradually decayed in Germany until, in 1830–40, they were, by general consent, in worse condition here than in any enlightened country in Europe, while animal magnetism, cranioscopy, and homœopathic vagaries sprung up, grew rank and struck deep root in soil in which, if anywhere, only minute and painstaking investigations of the physical conditions of health and disease should be cultivated. Only for the fundamental dichotomy of sensation and motion was solid physiological ground won later by the great discovery of Charles Bell, that the posterior spinal nerves were sensory, and the anterior nerves motor.

It will help us to understand another element of the greatest importance for our theme to go back to the seventeenth century and to remember that, as Plato is the philosophic father of most spiritualistic tones of thought, so Des Cartes may be said, in general terms, to have introduced into the modern world that form of dualism which has superseded Platonism, and proposed the fundamental problem with which philosophy has been so largely occupied ever since, viz., the mediation between mind and matter, soul and body, thought and being. We will not here pause to trace out the repressing effect which the metaphysical theories which centre about the theory of knowledge have had upon legitimate psychological studies. It is important, however, not to forget that Des Cartes was led chiefly by the exigencies of his system—according to which mind as thought could have nothing in common with matter as extension, and must, therefore, be brought into a forced union with it—and partly by his physico-mathematical tastes and studies to describe the body as a machine, and that this characterization had great influence upon minds of an empirical order. Great and preponderating as were the powers he assigned to the soul, the limitation of its seat to a single part, and the relegation to it of only those activities within the body not strictly mechanical, was a step of great importance. Besides this, Des Cartes' whole habit of mind, his inability to think, save with visual and mathematical concepts, his physical conception of physiology and the form and nature of particles were, no doubt, of much direct and indirect influence in forming the mechanical, or so-called iatro-mathematical school of medicine. A more direct stimulus to this school was given by the brilliant demonstrations of Galileo, while Harvey, Bacon, the revival of fine arts in Italy, and the unfruitfulness of chemical-humoral conceptions expressed and strengthened the tendency it represents.

The modern mechanical school of physiology was founded by Borelli, whose chief work on The Motion of Animals appeared in 1670. The bones he described as levers, and the swelling of muscles by the nervous fluid propelled into them from the brain was the motive power. He estimated how much force is lost by the unfavorable purchase of muscles, and compared the force used by different muscles. He first demonstrated that the act of breathing was a process in which the lungs are purely passive, and analyzed composite motions with a thoroughness unsurpassed till Weber. The movement of the blood he referred to static and hydraulic principles, tried to estimate the force of the heart's movements, and knew that it was greatest in the lateral walls, while the apex was comparatively motionless. Even digestion, he inferred from

the stomach of birds, consisted largely of detrition, while he calculated in pounds the powers of the walls of the stomach. Secretion he considered as a process of sifting depending on the different diameter of small vessels. Borelli's pupils, like their master, restricted themselves to the most familiar natural forces and mechanical principles, in their attempts to explain organic processes. Hoffman, who also studied mathematics as a preparation for medicine, in establishing this school in Germany, added to the ordinary material elements the hypothetical ether which Huyghens had just introduced. Besides permeating the blood, ether has its own peculiar circulation through the nerves. This fluid moves and is governed by the central *anima*, strictly in accordance with higher mechanical laws, which are, however, not yet well understood. Hoffman's speculations concerning the animal ether, which he expressly identified with the sensory soul, gave his system a dynamic cast inherited directly from Leibnitz, whom he admiringly studied, and this tended greatly to obscure the mechanical principles, upon which he always insisted, and to give his teachings, which have had great influence in Germany, some points of analogy with those of Stahl, his famous adversary. As the nervous system became known and gradually assumed a supreme position among the tissues, many mechanical conceptions of the processes which underlie its functions were expressed in place of the old idea that nerves contracted and lengthened in occasioning motion. They were sometimes said to vibrate like the strings of a harp; or the molecules within them were thought to oscillate; or their subtle fluids to mingle with others by diffusion. Irritability, one writer explained, was a modification of general attraction; and others thought nutrition and excretion were due to attraction and repulsion.

Part of the energy of the mechanical school went to seed in the shallow writers of the *erclairissement;* some of it can be traced in monographic works on light and vision, etc., while among many wiser observers the conviction gained ground that chemistry and mechanical science were not yet sufficiently developed to explain the more recondite processes of organic life, and they naturally turned, therefore, to the purer and broader forms of theoretical empiricism represented by Bacon and Locke, and to the development of the practical side of their respective professions. During the present century, however, mechanical methods have attained a remarkable development in the German experimental school of physiology which has recreated the art and science of medicine in that country, equipping it with manifold thermal, electric, hydrostatic, surgical and other apparatus and

methods, and enriching the world with the multitude of facts grouped under the names neuro and psycho-physics, physiological optics and acoustics, myology and physiological chemistry. Very prominent among the important physiological conceptions of this century is Marshall Hall's theory of reflex action, which first introduced a mechanical principle to explain the functions of the nervous centers of the spinal cord. The discussion of this most important conception we must reserve for a later chapter.

Here, however, belongs a brief reference to one of the most interesting of all attempts to interpret physiological processes by the aid of physical principles. The phenomena of animal electricity were first studied in a part of the reflex apparatus of a frog. If they have not explained all that was once hoped, it was these studies which first introduced exact methods into the investigation of the functions of the nervous system. With the collapse of mesmerism in the French revolution the many speculations which had been rife concerning the relation between the magnetic and vital phenomena were quickly forgotten until in 1791, a new direction was given to physiological physics by Galvani's conception that the animal body, pre-eminently the nerves, was the seat of a peculiar and independent sort of electricity, probably secreted chiefly in the brain. He believed the inner substance of the nerves to consist of a very subtle and fluid lymph peculiarly adapted to conduct electricity, and which was inclosed in a non-conducting substance. This electricity was stored up in the muscles as in Kleist, or Leiden jars, to which the nerves were the conducting wires. The outer surface of the muscles was negative, their inner surface, where the electricity accumulated, was positive. Motion was caused when this fluid was drawn from the interior to the exterior of the muscles along the nerves so that the cause of every contraction is like the discharge of a Leiden jar, the negative surface fibres of the muscles being peculiarly irritable. Although this theory was not strictly in accordance with the facts he had observed, the greatest popular interest was again aroused. "Wherever there were frogs," says Du Bois-Reymond, "and wherever two scraps of heterogeneous metal could be found, every one sought to see for himself the miraculous re-animation of mutilated limbs. Physiologists believed their ancient idea of a vital force had become tangible, and physicians, influenced by Galvani's too facile attempts to explain all sorts of nervous diseases,— sciatica, tetanus and epilepsy,— thought no cure hence forth impossible." Volta, who was already an experienced electrician, easily demonstrated that the electricity which Galvani had at first observed came from metals and

not from the animal. The former had the best of the controversy until Galvani found that when the sciatic nerve was brought into contact with the muscle a contraction occurred without metals. Volta still insisted that the current was not pre-existent in the animal, but was developed by the contact of different fluids in the tissues. After repeating the experiments of Volta and Galvani with many variations, Humboldt came to side with the former, and although his observations fill two volumes, they add little that is new in fact or valuable in theory.[1] In 1799, the year after Galvani's death, Volta discovered the pile which bears his name. His erroneous contact theory, (that whenever two heterogeneous substances are brought into contact one of them assumes a positive and the other a negative electrical condition), absorbed scientific interest, and galvanism was forgotten. The frog-pile was discovered, and many attempts were made to explain animal electricity by physical hypothesis.

At last, after applying Ampère's astatic double needle to Schweiger's multiplicator, which gave a far more delicate test for detecting the presence of electricity than had hitherto been known, Nobili, in 1826, demonstrated the frog-current which Galvani lacked the physical apparatus to do. The muscle and nerve, or the head and feet of a frog, each immersed in a tiny cup containing salt solution, into which the wires of the multiplier were introduced, caused a permanent deviation of the needle, demonstrating a constant current from the muscles to the nerves, and from the head to the feet of the frog. This current he believed to be of thermo-electric origin, flowing from the warmer to the colder part.

The subject was taken up and advanced by Matteucci (to whom Du Bois-Reymond, in the historical sketch just referred to, does much injustice), by Valentin and Reymond himself. The electrical properties and processes in nerves and muscles, at rest and in action, has now become one of the most complicated of physiological problems, while the pre-existence of the current in the natural condition of the tissues, which Reymond advocates, and his hypothesis of polar molecules arranged longitudinally through nerve and muscle fibers like a series of magnets to explain the phenomena of electrotonus and the development of the electrical current, are rendered very questionable by the experiments of Hermann and Englemann. In 1850, ten years after the publication of Reymond's investigations, the time of the transmission of irritation along nervous fibers was first measured, and found to be so great that all thoughts of identity or parallelism of electricity and the nervous energy efficient in sensation and motion—a con-

[1] Versuche über gereizte Muskel- und Nervefasern. Berlin, 1797.

ception which had considerable influence in inspiring and directing investigations up to that point—had to be abandoned. The wave of negative variation of the neural current, which moves only about 28 metres per second, is now considered as merely the accompanying sign or exponent—and the only one we have—of a series of processes which constitute every nervous impulse, the ulterior nature of which is as yet inscrutable. Even the nature of the processes of muscular contraction which, besides the far slower negative wave, is attended by thermal, chemical and dioptric, as well as molar changes, is as yet only conjectural.

The application of electrical stimuli to animal tissues has proved the most fruitful of all physiological methods, and it seems at first strange that its use in reflex studies should have been so very recent, and scarcely less so, that, during the earlier investigations of galvanism, the phenomena of reflex action should have attracted so little attention, although it is evident from causual reference that it was often observed. The reasons it is hoped will become apparent as we proceed. Meanwhile we may observe that it is the exact mechanico-empirical method that has accomplished everything, almost without exception, that has been done in the field of physiology. Just so far as experimenters have added explanations and theories to their demonstrations, their work has crumbled and been forgotten, while just so far as they directed and confined their labors to the pure and clear presentation of typical facts and their conditions, in such a way that others could readily find and reproduce them at will, their contributions have been useful and permanent.

A new physical method is the most important contribution that can be made to science, and through it to the sum of human knowledge and happiness. This is no less true of neurological than of other studies. Diseases have been classified in genera and species like plants, according to the medicines which it was thought were salutary, according to the most elaborate schedules of subjective "symptomatic" feelings, according to the organs they affected, according to *apriori* philosophical schemes, but a true natural basis of classification was reached only when the forms of cell-change or decay peculiar to each was known. In a scarcely less rude and uncritical way psychic faculties and processes have long been classified, and if the latter are ever to be soundly based on the varieties of structure and process in the nervous elements or substrata, while we shall then feel surer of our knowledge of them and have a method of study which may reveal much now undreamed of, only those most deeply versed in mechanical aspects of things and in the capability

of physical methods, can understand how unaffected they must forever leave all the ideal *goods* which those who comprehend them least profoundly so often think imperiled.

The rapidity with which nervous processes traversed the nerves was thought by the physiologists of the last century to be analogous to that of light or else of lightning. Some said it was as much more rapid than the blood as the nerve fibers were smaller than the aorta, and some argued that it must be absolutely independent of time. Haller falsely assumed that between every two contractions the way between muscles and the brain must be passed and repassed, and estimated this rapidity at 9000 feet per minute. As late as 1844, Johannes Müller wrote "we shall never have the means of measuring the rapidity of nervous processes, because we can never compare immense distances from which the rapidity of a process in the nerves, in this respect analogous to that of light, can be computed;" and again, "the time in which a sensation-process from the periphery to the brain and cord, and the reaction upon the peripheral parts by contraction follows, is infinitely small and immeasurable." One of the earliest achievements of Helmholtz, however, was in measuring these rapidities. Although his apparatus, compared with that now in use, was very imperfect, his result—that irritations are propagated along motor nerve fibers at the rate of 27.75 metres per second—was tolerably accurate. Most of his experiments were made by stimulating the sciatic nerve of a frog at points alternately near and far from its entrance into a muscle, which recorded upon a swiftly revolving drum the movement when the resulting contraction began. The effect of this discovery upon the conception of the nature of nervous action in general was great. Helmholtz wrote "as long as physiologists thought themselves compelled to refer nervous processes to the diffusion of an imponderable or psychic principle, it might seem incredible that the rapidity of the current within the short distances of the animal body should be measurable. Now we know from the investigations of Du Bois-Reymond on the electromotive properties of nerves, that that activity which mediates the propagation of an irritation is at least very closely connected with a changed arrangement of their material molecules, in fact is perhaps essentially conditioned by it. According to this the conducting of impulses in nerves would fall into the class of self-propagating molecular processes of ponderable bodies, such as, e. g., the transition of sound through the air and elastic substance, or the gradual burning of a fuze." ED.